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as constant as possible including the delay between the end of one presentation and the beginning of the next one.

Samples of typical stimulus presentations and evoked responses are given in the following three figures. Figure 1 shows a high speed inkwriter recording of the amplitude envelope of the emissions by the investigator and those evoked from Tursiops. In this case of three bursts apiece, the Tursiops is shortening up the duration of the first two bursts and equaling or matching the duration of the third burst. The whole evoked response is shorter than the stimulus presentation.

Figure 2 shows something of the matching abilities with regard to 'number of bursts' taken directly from the experiment. The first presentation and response each have five bursts, the second has four and the last has three. This recording also shows an analysis of a narrow band of frequencies around 200 cps for the investigator's presentation and around 7 kc for the Tursiops reply. There is very little overlap in these two bands of one for the other; hence, one can separate the emissions by each and relate them to the total output (at all frequencies) recorded in the first (upper) trace. To correctly count the relationship between stimulus train and evoked response train requires careful listening to the tape at slowed speed so as to be able to interpret all of the deflections on the inkwriter record. One typical artifact to be avoided is the sounds of the splashing water shown as "W" on these figures.

Figure 3 shows a particularly long train of 10 bursts in the presentation and 10 bursts in the evoked response. An individual Tursiops has been able to go as high as 12 responses for 12 presented bursts.

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Measurements of the duration of the total bursts in the presentation versus the total time of the elicited reply show a relatively narrow scatter about the equal values. (Figure 4)

The number of bursts in the presentation related to the number of bursts elicited, for a total of 40 presentations and 198 bursts presented is shown in Figure 5. Most of the presentations are matched, number for number. It is also to be noted that the errors peak at a value of one and fall off rapidly at 2 and 3, i.e., if the human gave 4, the Tursiops when mistaken gave either 5 or 3, and rarely 2 or 6.

In addition to the above variables several frequency channels have been analyzed continuously on these records. Such analyses, in brief, show that Tursiops tends to emit from 1000 cps to 10,000 cps in response to stimulus trains from the observer which cover the region from 100 cps to approximately 4000 cps. Complete overlap occurs with high energy from investigator and from Tursiops in the region of 2300 to 3000 cps.

The importance of these results can probably be best understood when one realizes that such a performance as the above physically measured one has not been demonstrated for any other organism except *Homo sapiens*. Tursiops' ability to copy numbers of trains, durations of trains, and (some-what) the frequencies of sounds within the trains apparently has not been matched by any other organism, including parrots, mynah birds, anthropoid apes, etc. The onset of such behavior in *Homo sapiens* can begin anywhere from 12 months to 24 months of age. The age at onset of such a capability in Tursiops truncatus is yet to be determined.

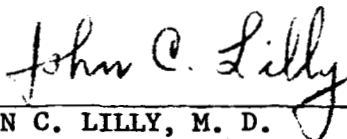
Thus, we have demonstrated some of the adaptability and flexibility of the conditionable behavior in the vocal mode of Tursiops. These experiments

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are continuing, exploring the statistical distribution of the quantities observed. Additional experiments with frequency multipliers and dividers are planned. A hydrophone with a small FM transmitter on it has been devised and is to be used in these experiments to increase the technical quality of the recorded information from Tursiops, i.e., to eliminate room reverberation, water noises and other sources of airborne sounds.

Respectfully submitted,



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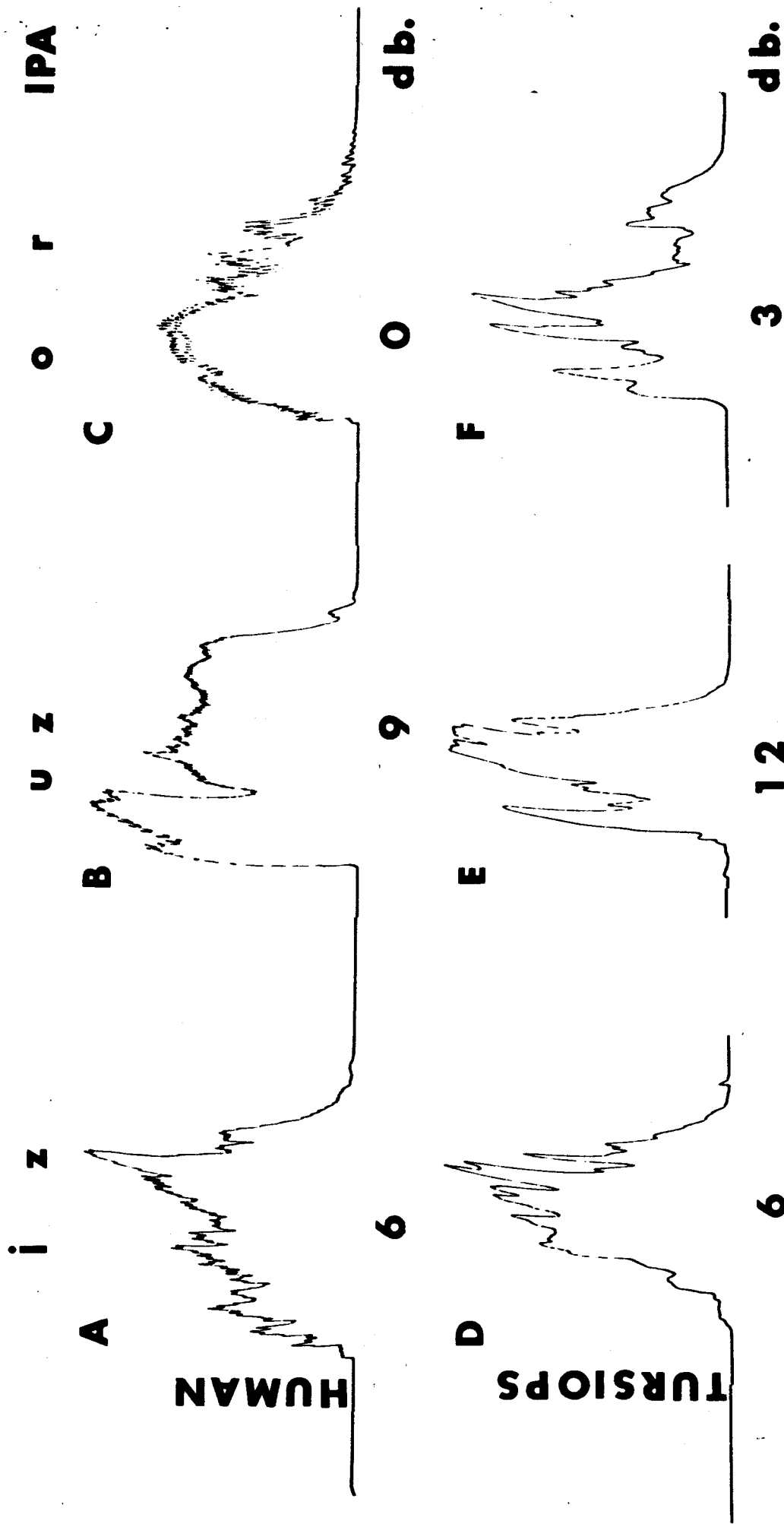


FIGURE 1. Inkwriter record of bursts three to three match: amplitude envelopes of all frequencies. Syllables "iz," "uz," and "or" in presentation; replies match number, with shortened responses to first two stimuli and matching duration of third.

0.5sec

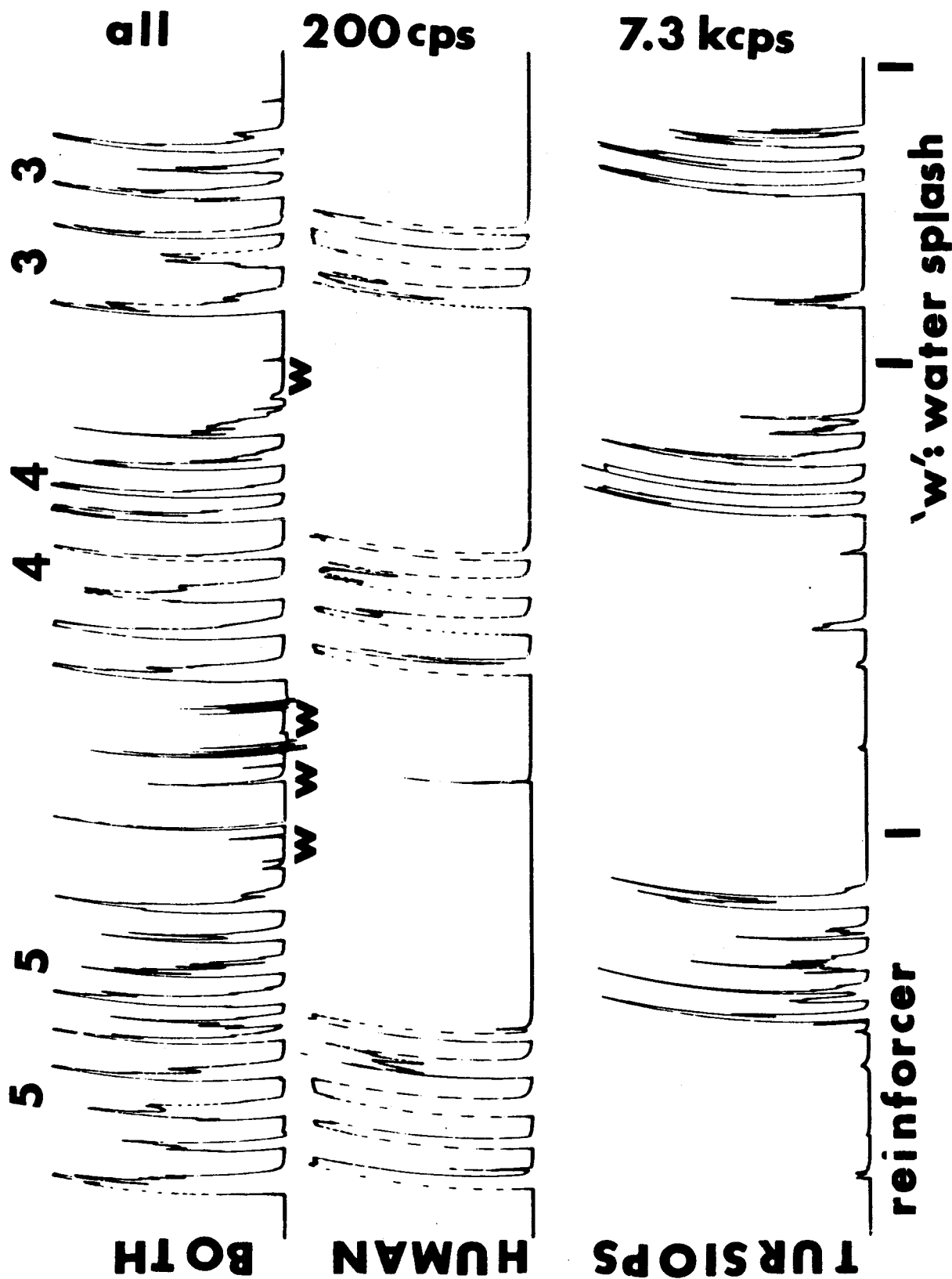


FIGURE 2. 3 Presentations: number and durations matched in replies. (200 cps narrow band distinguishes human from Tursiops; 7.3 kcps narrow band distinguishes Tursiops from human emissions; top trace is envelope of all frequencies of both emitters with AGC).

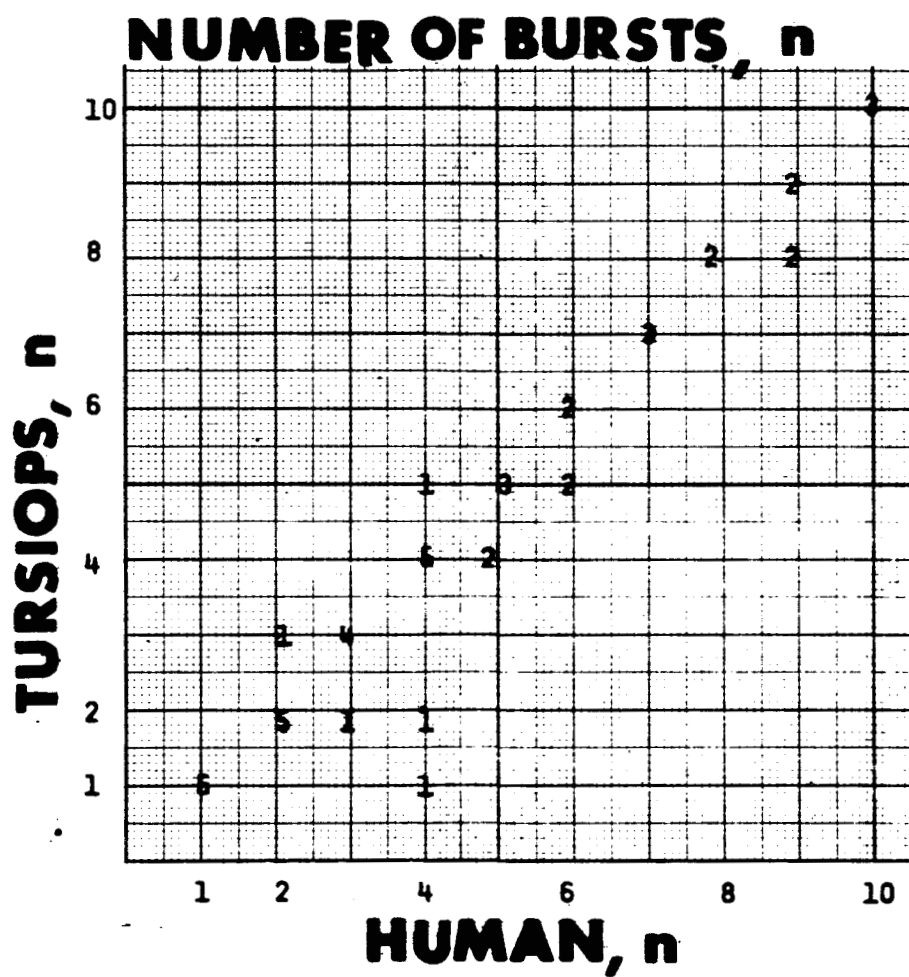


FIGURE 5. Distribution Curve of Numbers of Bursts in Evocative Presentation and in Evoked Reply.
(Same raw data as in Figure 4.)

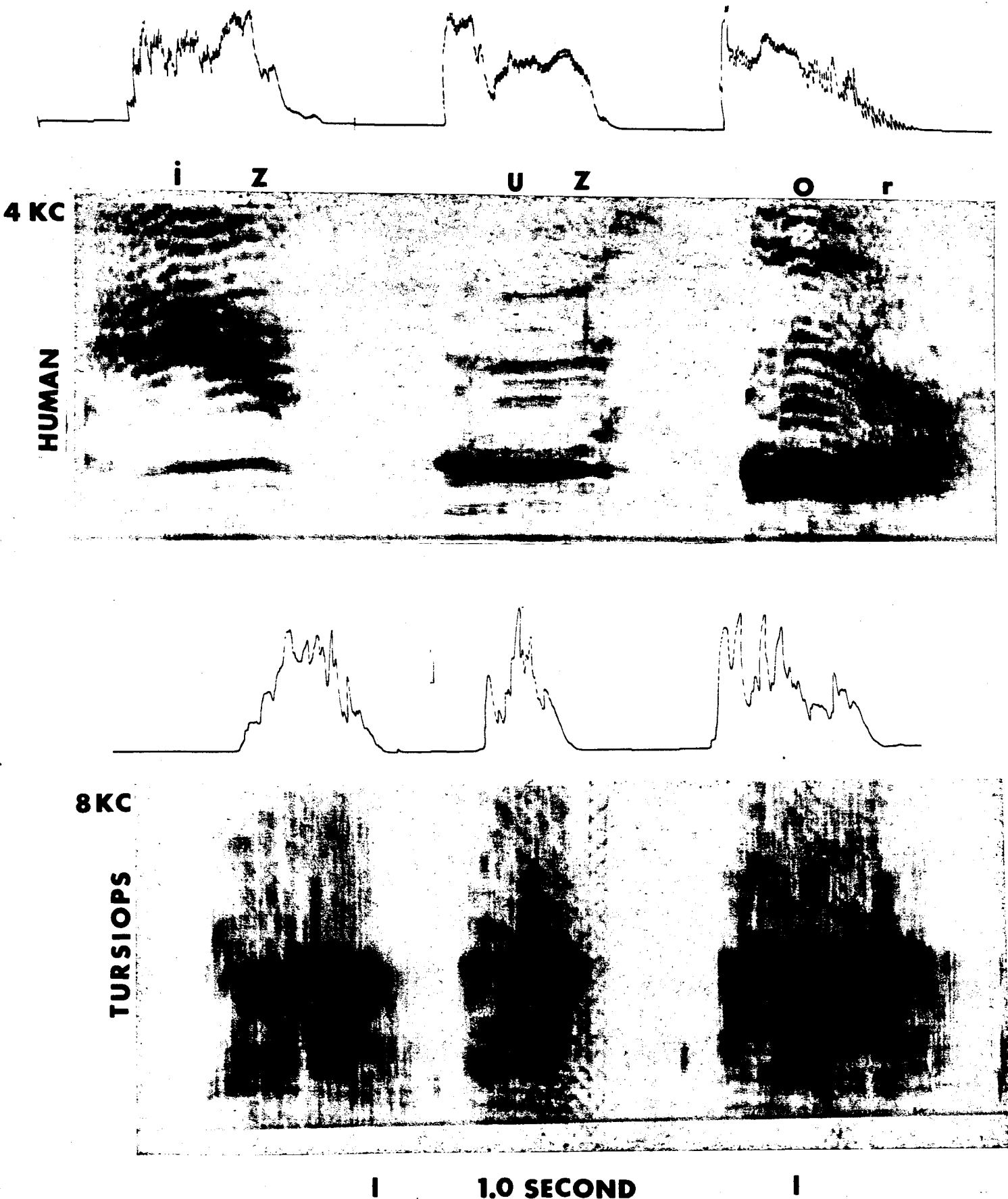


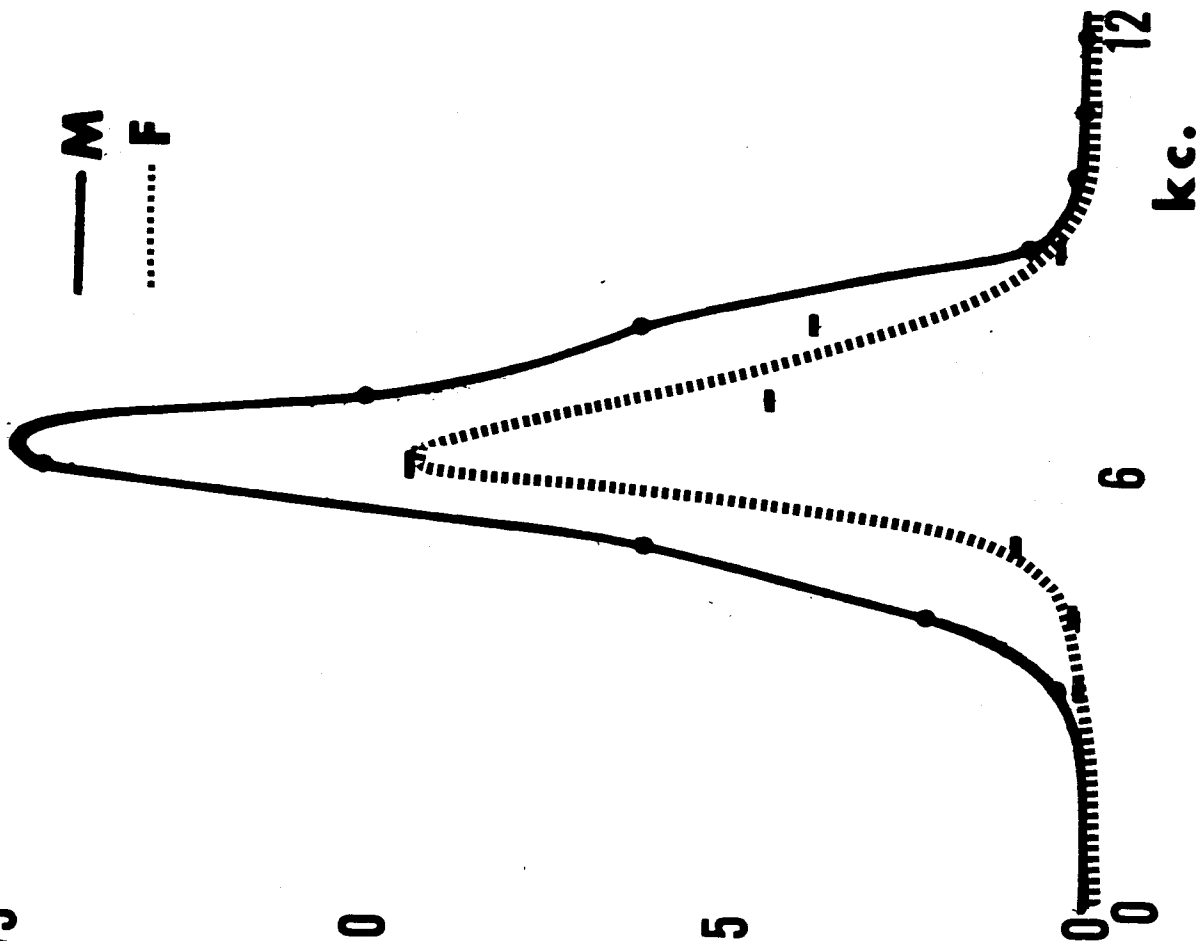
FIGURE 6. Sonic Spectral Analysis of Emissions. (Same series as in Figure 1). The human range is 4 kc; the dolphin range is chosen as 8 kc. to show its higher pitch. The human record is analyzed with the narrow band filter (45 cps) and the dolphin with the wide band filter (300 cps). (Kay Electric Co., Pinebrook, N.J. "Sonagraph"). The amplitude envelopes are adjusted to give equalization of the peaks.

ONSETS

75

INSTANCES

25



ONSETS

FIGURE 7. Natural Whistles of Tursiops in Exchanges. The vocal exchanges in the whistle mode between two Tursiops (male, "M," and female, "F") were recorded. The tape was analysed with the sonic spectrograph from zero to 24 kilocycles. The onsets, offsets, and peaks were measured; the data were arranged in 1 kilocycle bands and the instances counted where each considered part of the whistle intercepted each band. The above plots are the number of occurrences of each onset in each band. The next two Figures give the plots for the peak frequencies and the offset frequencies. In this Figure, the data show the most frequent onset is in the region of 6 kilocycles for each Tursiops.

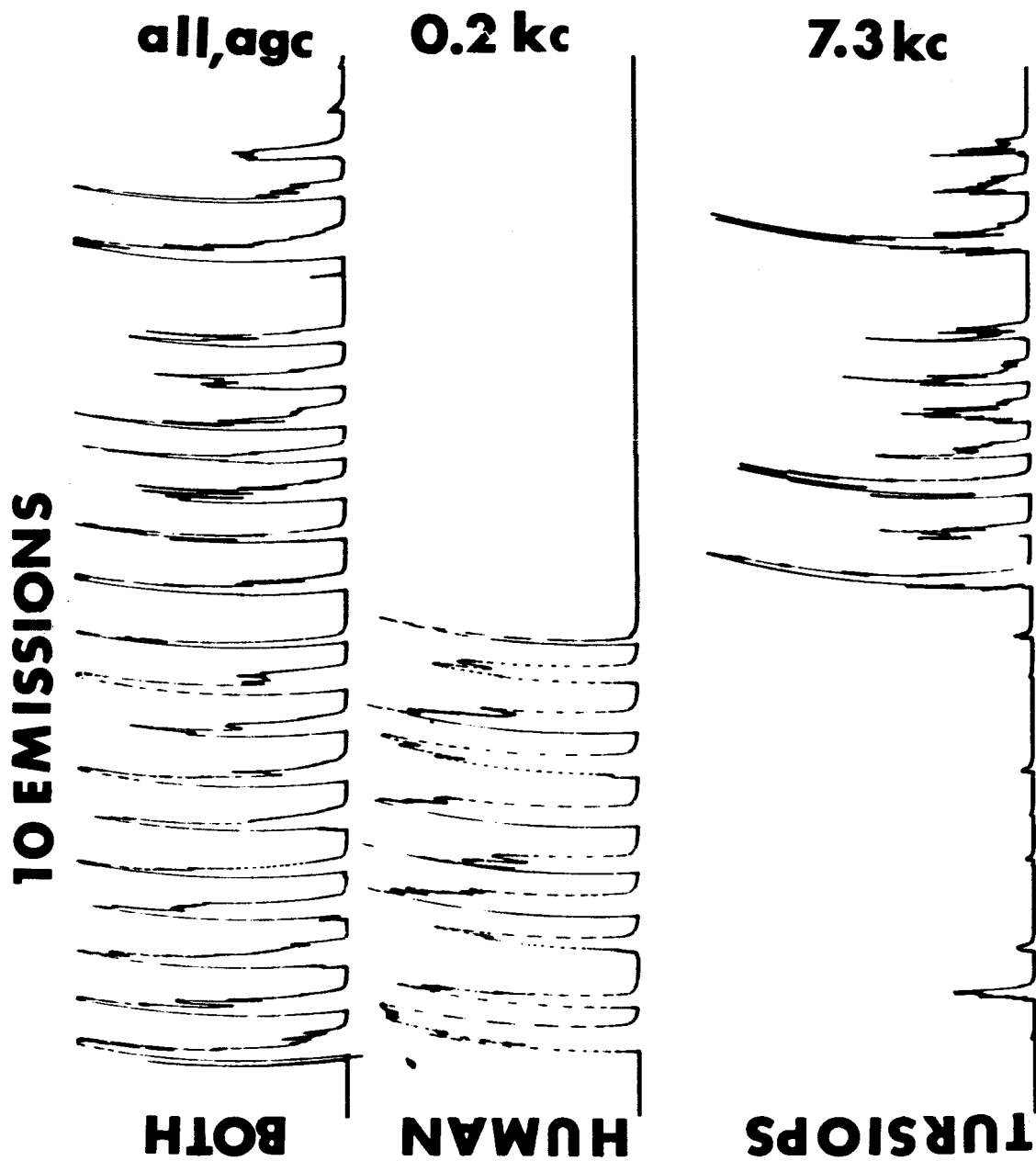


FIGURE 3. Ten bursts (emissions) matched in number and in duration.

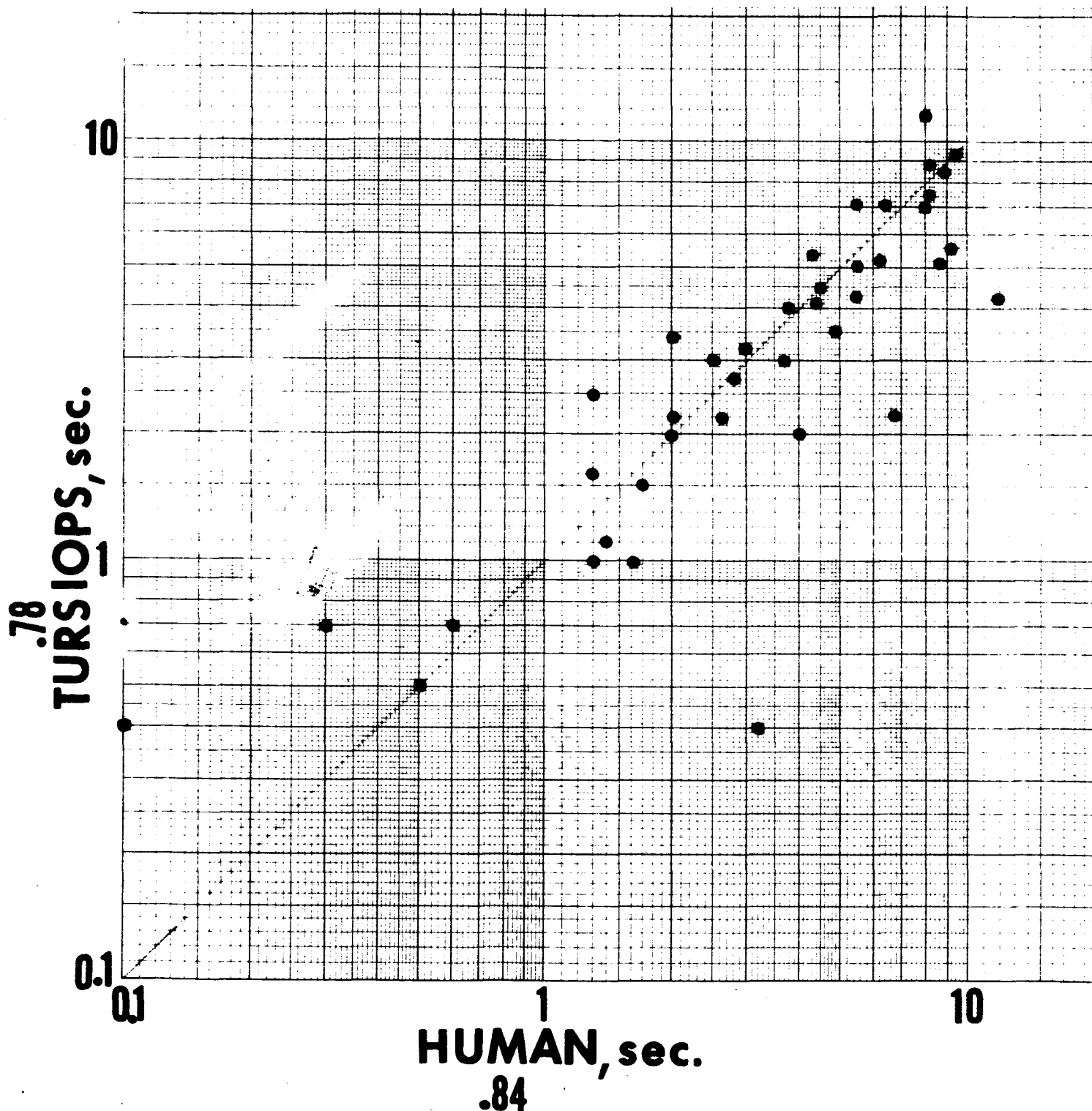


FIGURE 4. Duration of Evocative Stimuli plotted against duration of Evoked Response for forty exchanges (typical experiment).

PEAKS

30

INSTANCES

20

10

0

6

12

kc.

18

24

F

M

FIGURE 8. Natural Whistles of Tursiops in Exchanges. The peak frequencies reached by each animal were categorized in the 1 kilocycle bands. The frequency of occurrence ("instances") is plotted on the Y axis and the sonic peak frequency band on the X axis. The male (M) shows peaks in the "number of instances" in multiples of 4 kilocycles; the female (F) shows a gradually climbing curve to a peak at 21 kilocycles.

OFFSETS

INSTANCES

M

20

10

0

6

12

18

24

kc.

F

FIGURE 9. Natural Whistles of Tursiops in Exchanges. The number of instances of the offset sonic frequencies falling in each 1 kc band shows for the male (M) a similar periodicity to that of the peak frequencies (Figure 8). The female's (F) results are similar to those for the peak frequencies (Figure 8). Amplitude studies of the same data show that peak amplitude is generally reached and passed between the onset frequency and the peak frequency, and the offset is usually at a low amplitude (24 db. down from the maximum).


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The basic problems and orientation of this research have been evolving rapidly during the last year and a half. The project started with experiments designed to test the communication capabilities of Tursiops truncatus, as an example of an organism with a very large central nervous system. Investigations have been initiated on the natural underwater productions and of the elicited airborne sounds.

The orientation which has gradually evolved is that of seeking physically specifiable aspects of sonic exchanges between organisms. The advantage of physically specifiable variables is that no psychophysical judgments are necessary to obtain agreement as to certain aspects of the observed phenomena. The major effort in this project has been to explore several such physical variables. Among these are the frequency-amplitude-time-patterns, the time durations of 'presentations' or of 'stimulus groups' and the time of 'replies' or 'evoked responses,' the number of bursts in the stimulus train and the number of elicited bursts in the response train, etc.

Such investigations allow graphical representations, graphical recordings, quantitative measurements, and specification by numerical results. Some psychophysical tests of agreement between observers have been initiated (listener panel method).

The first case is that of underwater exchanges between two Tursiops; the methods employed are those published in the paper "Vocal Exchanges, Science, 134: p. 1873-1876, 1961. Since the publication of this paper the sonagrams of the whistles have been analyzed. The distribution of the frequency of onset, peak frequency and frequency of offset are given in figures appended to this report.



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The analyzed whistles are those occurring during spontaneous exchanges between two Tursiops. It is to be noted that the distribution of onset frequencies has an occurrence peak at 6 kc and that the peak frequencies and offset frequencies are distributed more widely up to 24 kc, i.e., up to a frequency of 4 times the 6 kc frequency. These results do not include the harmonics of the fundamental frequency. As was stated in the above cited paper, harmonics of these basic frequencies have been detected up to 64 kc. The harmonics vary in less predictable ways than does the fundamental.

Power spectra of these whistles were investigated by means of a 30-channel sonic-ultrasonic analyzer with narrow bands observed simultaneously throughout this region. These show that the fundamental-to-the-first-harmonic power ratio is of the order of 25 decibels to 60 decibels. The maximum energy is emitted between 8 to 14 kc.

Some clicking exchanges have been investigated as well as the whistles. Some of the clickings correspond in both amplitude and frequency to the same domain as the whistles. Other clickings peak in the region from 28 kc to 45 kc, falling off rapidly beyond 33 kc at a rate of about 6 db per octave.

An investigation of the very much higher frequency components, "ultrasonic clickings" was done with two transducers whose peak sensitivity was at 145 kc. These results showed that when Tursiops emits at 140 kc the field intensity straight ahead of the upper jaw at 6 cm is about 40 decibels higher than that directly lateral to the head at a point 6 cm from the external auditory meatus.

BEV K.

The airborne sounds were investigated in a more limited frequency region extending from 100 cps to approximately 8 kc. Experimental research concentration was on the elicited airborne sounds in this frequency region. This work follows the findings presented in the paper "Vocal Behavior of Tursiops" in the Proc. of the Amer. Philosophical Soc., 106: 520-529, 1962.

The experimental procedures to elicit airborne sonic outputs from Tursiops are standard methods of operant conditioning, utilizing, where possible, a food reinforcer, and a limited controlled environment. Initially the investigator makes the sonic presentations and gives reinforcement at the proper instant after eliciting a desired response. The transition to a program tape instead of the human investigator for the presentation of the stimuli has been successfully achieved. An automatic electronically controlled food dispenser has been designed, built and used for introducing the reinforcement. Such a method (which eliminates the presence of the investigator beside the Tursiops) is being perfected in order to eliminate the complex mutual stimulation and responses between the Tursiops and the investigator.

The stimuli are chosen so as to vary systematically through a set of parametric values, i.e., for sine waves, frequency is varied while amplitude and duration and number of trains in a group are held constant. Then while frequency, duration and number of bursts in a group are held constant, amplitude is varied. In the case of sounds emitted by the investigator, nonsense syllables are paced by a flashing light and read either into a tape machine or to the Tursiops. Lists are made up in advance, randomized as to the particular variable of interest; for example, with respect to the number of bursts per presentation. Everything else is held